

Risk Factors for Anterior Cruciate Ligament Injury in High School and College Athletes

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Abstract: *The anterior cruciate (ACL) is the most frequently ruptured ligament of the knee. Some authors have suggested that excessive internal tibial rotation concomitant with hyperpronation of the subtalar joint during stance and inherent knee joint laxity may predispose an athlete to knee injury. Over a period of 2 years, we identified 14 ACL-injured football players and eight ACL-injured female basketball players and gymnasts. We matched them by sport, team, position, and level of competition with 22 athletes without history of ACL injury. Measures of navicular drop, calcaneal alignment, and anterior knee joint laxity with a KT-1000 were obtained from the uninjured knee of the ACL-injured athletes and compared with measures obtained from the ACL-noninjured athletes. ACL-injured athletes had greater amounts of navicular drop, suggesting greater subtalar pronation and greater anterior knee joint laxity. Discriminant analysis and multiple regression indicated that these variables correctly predicted injury status for 87.5% of the females and for 70.5% of all cases. These*

results suggest that the more an athlete pronates and the greater the anterior knee joint laxity, the greater the association with ACL injury.

The anterior cruciate ligament (ACL) is the most frequently ruptured ligament of the knee.¹² The mechanism of ACL injury is often described as noncontact. Previous authors have reported that 78%²⁰ and 71%⁴ of ACL-injured patients described noncontact mechanisms of injury. It has been suggested that excessive internal tibial rotation concomitant with hyperpronation of the subtalar joint during stance⁴ and inherent knee joint laxity¹⁷ may predispose an athlete to ACL injury.

While much has been written on injury to the anterior cruciate ligament, little attention has been devoted to understanding the mechanism of injury.⁹ A greater understanding of the mechanics of injury are needed as we work to prevent, and improve treatment of, injuries to the ACL.⁹ We conducted this investigation to develop a better understanding of the risks of ACL injury. For, if our efforts of prevention are to succeed to their fullest potential, we must be able to identify those athletes at greatest risk.

The purposes of our study were: 1) to determine if clinical measurements used to assess pronation and anterior translation of the tibia on the femur discriminate between ACL injured and ACL-noninjured athletes matched for sport, team, and position, and 2) to identify those measures which are the strongest discriminators between the two groups.

Methods

We assessed the uninjured lower extremity of 14 ACL-injured male high school and college football players and eight ACL-injured female high school- and college gymnasts ($n = 6$) and basketball players ($n = 2$) using clinical measures indicative of pronation and anterior displacement of the tibia on the femur. All of the ACL-injured females and 10 of the males clearly described a noncontact mechanism of injury. We also selected an equal number of athletes, matched for sport, position, and playing time, without history of ACL injury, and assessed both lower extremities. All subjects provided informed consent in compliance with university guidelines.

Data collection was conducted in two phases during a 2-year period. In the first phase, 14 high school and college football players (19.1 ± 6.0 years, 73.2 ± 3.3 in, 211.0 ± 47.9 lb) with a history of unilateral ACL injury, confirmed arthroscopically or during arthrotomy, were identified. We matched the injured athletes with 14 football players (18.1 ± 1.6 years, 72.3 ± 2.9 in, 199.6 ± 36.6 lb) without history of a knee injury more severe than a first degree sprain, by team, position, and extent of participation.

In the second year of data collection, we identified and matched eight ACL-injured female athletes (six gymnasts and two basketball players) (19.5 ± 1.7 years, 64.6 ± 3.7 in, 128.0 ± 17.0 lb) with eight uninjured athletes (19.0 ± 1.2 years, 63.3 ± 2.6 ins, 126.9 ± 12.8 lbs) by sport, injured leg, and level of competition.

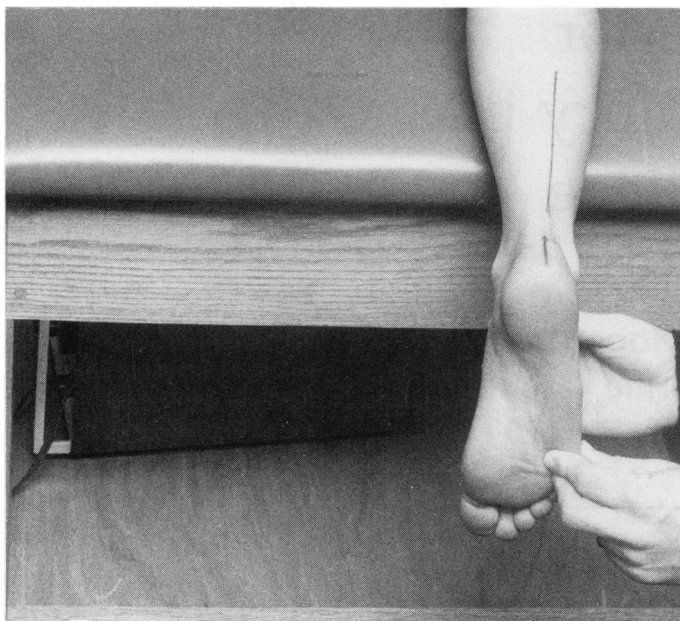
We obtained measures of calcaneal alignment changes in stance, navicular drop, and anterior translation of the tibia on the femur bilaterally from the ACL-noninjured athletes and from the ACL-uninjured lower extremity of the ACL-injured athletes. We selected the uninjured lower extremity so that all measures came from the same extremity and so that athletes whose weight bearing was restricted secondary to surgery could be included in the study.

Calcaneal alignment was assessed in a nonweight-bearing position by having the athlete lie prone and place the contralateral leg in the figure 4 position (see Figure). The lower one third of the leg was bisected from the musculotendinous junction of the triceps surae to the Achilles tendon. The medial and lateral tubercles of the calcaneus were

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Position for assessment of nonweight-bearing calcaneal alignment.

palpated, and the calcaneus was bisected. Subtalar neutral was identified by grasping the fourth and fifth metatarsal heads and palpating the talus as described by Magee.¹⁴ A standard goniometer was used to estimate, to the nearest degree, the angle between the bisection of the leg and bisection of the calcaneus. The angle between the bisection of the leg and calcaneus was then measured with the athlete positioned full weight bearing to assess change in calcaneal alignment during stance.

We measured navicular drop with Brody's⁵ technique; ie, measure the distance between the navicular tuberosity and the floor with the athlete sitting and the subtalar joint in neutral position and again with the athlete standing full weight bearing on the limb being assessed. The difference in the two measures is the navicular drop.

Using a KT-1000 knee arthrometer (MEDmetric Corp, San Diego, CA), we measured anterior displacement of the tibia on the femur. With the athlete positioned supine and the knee flexed approximately 20°, three measures of anterior drawer were obtained using 20 lb of force applied through the handle of the arthrometer, and three measures were obtained with maximal manual force applied to the posterior calf at the level of the proximal strap of the KT-1000. Means of the three measures with each loading force were used for further analysis. Within each phase, the same investigator performed all measurements with

the KT-1000 in an effort to maximize the reliability of the measurements.

Data Analysis

In the first phase, we analyzed the data from the uninjured football players using analysis of variance with repeated measures to determine if significant differences existed between the right and left lower extremities. Measures of calcaneal eversion, navicular drop, and anterior translation of the tibia on the femur obtained using the KT-1000, were analyzed with discriminant analysis and multiple regression. Classification of results tables indicated whether injured and uninjured athletes were correctly classified, based on the discriminant analysis. Chi-square analysis was conducted on the classification of results table to determine if the regression equation predicted group membership significantly better than chance. Finally, using a multiple linear regression analysis, we determined the portion of variance in group member-

ship that was explained by the predictor variables.

We analyzed the data from the female athletes in the same manner except that measurements of ACL-noninjured athletes were matched to the uninjured side the ACL-injured athletes. Finally, we combined and analyzed the data from the male and female athletes using the statistical methods described above.

Results

There were no significant differences between right and left lower extremities of uninjured football players for calcaneal position, navicular drop ($F(1,13) = .67, p = .43$), or the KT-1000 measurements with 20 lb of force ($F(1,13) = .12, p = .73$) and maximum manual force ($F(1,13) = 1.86, p = .20$). However, two of the athletes had a difference in navicular drop greater than 2 mm and four had differences in KT-1000 measures greater than 3 mm at both loading forces. Because most of these athletes had minimal bilateral differences, right and left side values were averaged for data analysis.

Discriminant analysis of the data from the football players indicated that navicular drop, anterior drawer with 20 lb of force, and maximum manual drawer were the best predictors of group classification. Group means and standard deviations appear in Table 1. Conical correlation between group membership and the discriminant score was .46 ($p = .11$). The classification of the athletes into ACL-injured and ACL-uninjured groups resulted in 71.4% being correctly classified (Chi-square = 7.43, $p < .01$; Table 2). Regression analysis revealed that 22% of the variance in group membership was explained by the three predictor variables.

Discriminant analysis of the data from the female athletes indicated that navicular drop, anterior drawer with 20-lb force, and maximum manual

Table 1.—Navicular Drop, KT-1000, and Calcaneal Eversion in Stance Values for ACL-injured and ACL-noninjured Football Players

	Navicular drop (mm)	KT-1000 20-lb force (mm)	KT-1000 maximum manual (mm)	Calcaneal eversion in stance
Uninvolved limb of ACL-injured	8.4 ± 4.2	5.0 ± 2.6	6.5 ± 3.3	3.9 ± 2.8°
ACL-noninjured	5.9 ± 2.4	4.4 ± 2.1	4.8 ± 2.2	4.5 ± 2.4°

Table 2.—Classification of ACL-injured and ACL-noninjured Football Players Through Discriminant Analysis

Actual group	Predicted group membership		Total
	Injured	Noninjured	
Injured	8	6	14
Noninjured	2	12	14
Totals	10	18	28

71.4% were classified correctly. Chi-square = 7.43, $p < .01$.

Table 3.—Navicular Drop, KT-1000, and Calcaneal Eversion in Stance Values for ACL-injured and ACL-noninjured Female Athletes

	Navicular drop (mm)	KT-1000 20-lb force (mm)	KT-1000 maximum manual (mm)	Calcaneal eversion in stance
ACL-injured	5.0 ± 2.5	5.3 ± 2.6	6.1 ± 2.7	3.9 ± 1.3°
ACL-noninjured	3.0 ± 1.1	3.8 ± 2.2	3.8 ± 1.5	5.9 ± 1.6°

drawer were predictors of group classification. Group means and standard deviations appear in Table 3. Conical correlation between group membership and the discriminant score was .71 ($p = .07$). The classification of athletes into ACL-injured and ACL-uninjured groups resulted in 14 of 16 (87.5%) being correctly classified (chi-square = 9.00, $p < .01$; Table 4). Regression revealed that 60% of the variance in group membership was explained by the predictor variables.

When the data from the football players and female athletes were combined for analysis, the conical correlation between group membership and the discriminant score was .45 ($p = .03$). The classification of athletes into ACL-injured and ACL-uninjured groups resulted in 31 of 44 (70.5%) being correctly classified (chi-square 7.45, $p < .01$; Table 5). Regression revealed that 20% of the variance in group membership was explained by measures of navicular drop and anterior knee joint laxity.

Table 4.—Classification of ACL-injured and ACL-noninjured Female Athletes Through Discriminant Analysis

Actual group	Predicted group membership		Total
	Injured	Noninjured	
Injured	6	2	8
Noninjured	0	8	8
Totals	6	10	16

87.5% were classified correctly. Chi-square = 9.00, $p < .01$.

Table 5.—Classification of Football and Female ACL-injured and ACL-noninjured Athletes Through Discriminant Analysis

Actual group	Predicted group membership		Total
	Injured	Noninjured	
Injured	15	7	22
Noninjured	6	16	22
Totals	21	23	44

70.0% were classified correctly. Chi-square = 7.45, $p < .01$.

Discussion

The results of our study suggest that greater knee joint laxity and subtalar pronation may be associated with an increased risk of ACL injury. These results are in agreement with the report who reported that ACL-injured patients, regardless of mechanism of injury, had greater navicular drop measures than a randomly selected group of patients with no history of ACL injury.⁴

Anatomical and biomechanical factors may increase stress placed on the ACL, thereby possibly increasing the risk of injury. Coplan⁶ demonstrated that subjects who pronated more had greater rotational motion of the knee, while Alm et al¹ reported that as internal rotation or external rotation of the knee increases, the absolute strength of the ACL decreases.

A narrow intercondylar notch of the femur has also been identified as being a risk factor for ACL injury.^{2,13,18} We did not assess notch width. While a narrow intercondylar notch may increase the risk of ACL injury and knowledge of such a condition may cause an athlete to limit athletic participation, screening of all athletes would be expensive. It is also unreasonable to perform notchplasty in an attempt to minimize the risk of ACL injury. Measures of navicular drop and anterior knee joint laxity can be more easily obtained. Pronation can be limited by selecting appropriate footwear or through the use of orthotics.^{3,19} If joint laxity is of concern, a training program can be prescribed to strengthen the muscles surrounding the knee. Thus, the risk factors we have identified can be screened for during a routine physical exam and potentially mitigated through orthotic management and exercise.

When conducting a physical exam, the reliability of the clinical measurement is of concern. Mueller et al¹⁶ calculated intraclass correlations and reported the intratester reliability of navicular drop to be .78 and .83 for the left and right foot, respectively.

Our average navicular drop measures were much lower than what Brody⁵ considered normal (10 mm) and abnormal (15 mm) in runners. However, Brody was discussing the effects of pronation on lower extremity overuse injuries in runners and presented the above values based on clinical experience as opposed to actual group mean values. Mean navicular drop values of 7.58 and 7.10 mm for left and

right feet have been reported.¹⁶ These values are similar to those we measured on ACL-injured (8.4 mm) and ACL-noninjured (5.9 mm) football players. The lower values for our female athletes were probably because most of our female subjects were gymnasts. These athletes were characteristically small in stature with low resting navicular tuberosity heights and less space for navicular drop.

Measures of calcaneal eversion in stance were not retained in the data analysis as predictors of ACL injury. While measures of calcaneal position in unilateral stance have been reported to have acceptable (ICC = .75) reliability,²¹ we found these measures are more difficult to obtain than measures of navicular drop. Therefore, it is reasonable to suspect that there was greater error when goniometric measures of rearfoot position were taken. Certainly greater measurement error could explain why navicular drop was retained in the analysis and goniometric measures of calcaneal position in stance were not.

The intratester reliability of measures of anterior knee joint laxity made with a KT-1000 has been reported to be good,^{7,10,11} while the intertester reliability is lower.¹¹ In our study, the same clinician took all measures of anterior knee joint laxity within each phase. Our mean knee joint laxity values are somewhat lower than,^{8,15} or similar to²² those reported by others. Whether these differences are due to sampling or measurement technique cannot be determined. However, regardless of these differences, our subjects with a history of ACL injury had, on average, greater measures of laxity in their uninvolved knee than did the matched counterparts.

In addition to pronation, anterior knee joint laxity, and intercondylar notch width, other factors, including playing surface and footwear, may affect the risk of ACL injury. Additionally, body weight, fitness level, and general athletic ability may impact upon the risk of injury. When data were combined, 20% of the variance in group membership (ACL-injured versus ACL-noninjured) was explained by measures of navicular drop and ante-

rior knee joint laxity, while other factors, not assessed in this study, accounted for the remaining 80%. Discriminant analysis forced group membership to be predicted, based upon the measurements we obtained. There was an association between navicular drop, anterior knee joint laxity, and ACL injury. Therefore, this analysis predicted group membership significantly better than chance. Because of the retrospective methodology of our study, we were unable to control for the factors noted above. We also made the assumption, based upon the analysis of the measures obtained bilaterally from the 14 ACL-noninjured football players, that the uninjured lower extremity of ACL-injured athletes is representative of the injured limb prior to injury.

Despite these limitations, the descriptive data and discriminant analyses suggest there were differences in inherent knee joint laxity and foot biomechanics between ACL-injured and ACL-noninjured athletes. We agree with Beckett et al⁴; further investigation is required to fully elucidate the impact of individual anatomical and biomechanical variations on the risk of ACL injury. If these results are substantiated by additional retrospective or large prospective studies, sports medicine practitioners may be able to reduce the incidence of ACL injury through preparticipation screening and use of exercise and orthotic devices to control knee and foot motion.

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